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THE NATIONAL AIR POLLUTION BACKGROUND NETWORK
1976-1980

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16. ABSTRACT The U.S. Environmental Protection Agency in cooperation with the U.S. Forest Service has established a network of air monitoring stations designed to measure levels of ozone in remote areas within the contiguous 48 states. There are currently eight sites, at various National Forests, which measure ozone, wind speed and direction, temperature, relative humidity, and solar radiation. This is a study of the network data gathered from 1976 through 1980 with analytical emphasis on the year 1979, for which the most complete meteorological and ozone records were available.

The mean ozone level for 1979 at these sites fell within the range of 0.025 ppm to 0.04 ppm. At most sites, there were several days in 1979 when hourly concentrations of ozone exceeded 0.08 ppm. The maximum 1-hour ozone concentration observed was 0.125 ppm. The report provides analyses of the statistical distributions of the ozone data from these remote sites, their relationships with local meteorological data, and the possible impact of air parcel history upon ozone concentration.

Examination of several individual days in 1979 with relatively high ozone levels using a back trajectory model showed that in almost all of these cases, the air had passed over large urban areas within the previous three days. The hypothesis is presented that high levels of ozone at remote sites may be due in part to the long range transport of ozone and/or its precursors.

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has the responsibility for: assessment of environmental monitoring technology and systems; implementation of agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency including the Office of Air, Noise, and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

The National Air Pollution Background Network was initiated at the request of the Office of Air Quality Planning and Standards. The project is being conducted jointly through an interagency agreement between the U.S. Environmental Protection Agency and the Forest Service of the U.S. Department of Agriculture. Results to date from the project are summarized in this report. The data are available to all interested researchers upon request to the National Aerometric Data Bank, Research Triangle Park, North Carolina.

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ABSTRACT

The U.S. Environmental Protection Agency in cooperation with the U.S. Forest Service has established a network of air monitoring stations designed to measure levels of ozone in remote areas within the contiguous 48 states. There are currently eight sites, at various National Forests, which measure ozone, wind speed and direction, temperature, relative humidity, and solar radiation. This is a report of the network data gathered from 1976 through 1980 with analytical emphasis on the year 1979, for which the most complete meteorological and ozone records were available.

The mean ozone level for 1979 at these sites fell within the range of 0.025 ppm to 0.040 ppm. At most sites, there were several days in 1979 when hourly concentrations of ozone exceeded 0.08 ppm. The maximum 1-hour ozone concentration observed was 0.125 ppm. The report provides analyses of the statistical distributions of the ozone data from these remote sites, their relationships with local meteorological data, and the possible impact of air parcel history upon ozone concentration.

Examination of several individual days in 1979 with relatively high ozone levels using a back trajectory model showed that in almost all of these cases, the air had passed over large urban areas within the previous three days. The hypothesis is presented that high levels of ozone at remote sites may be due in part to the long range transport of ozone and/or its precursors.

This report covers a period from May 1976 to December 1980, and work was completed as of December 1981.

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SECTION 1

INTRODUCTION

The National Ambient Air Quality Standard (NAAQS) for photochemical oxidants (measured as ozone) was initially set in 1971 at an hourly average concentration not to exceed 0.08 parts per million (ppm) more than once per year. At that time, only sparse ozone data were available from rural and remote areas, and ozone concentrations in these areas were believed to be low and inconsequential relative to the standard. Ozone from background areas also was thought to be largely removed by chemical scavengers upon entry into an urban environment. Subsequent investigations, however, have suggested that rural areas experience a greater range of variation than originally supposed and that ozone transported from rural to urban areas cannot always be disregarded. In the mid-1970's, the U.S. Environmental Protection Agency (EPA) conducted several field monitoring studies of summertime ozone concentrations in the Eastern U.S. (1,2,3). These studies confirmed that ozone concentrations in predominantly rural areas may occasionally exceed the NAAQS level then existing (the NAAQS level was changed to 0.12 ppm in 1979).

In response to these findings, EPA decided to establish a nationwide network of remote ozone monitoring stations. The network was started in 1976 as a joint effort between EPA's Environmental Monitoring Systems Laboratory (EMSL) and the Office of Air Quality Planning and Standards (OAQPS), located in Research Triangle Park (RTP), North Carolina. The Forest Service of the U.S. Department of Agriculture also agreed to participate in the project by providing three sites in National Forest (NF) areas and by performing routine operations at the monitoring stations. The network was expanded to six sites in 1978 and to eight sites in 1979.

Currently, the National Air Pollution Background Network (NAPBN) collects continuous measurements of ozone concentrations by the chemiluminescence technique at eight remote monitoring stations across the continental U.S. In addition, continuous measurements are made of wind direction and speed, temperature, relative humidity, and solar radiation at each site. Also, 24-hour particulate samples have been collected intermittently since 1980. Site locations are shown in Figure 1, and station descriptions are provided in Table 1. A report describing the network and the early data was published in 1978(4).

The network was established to provide a reasonably long-term and continuous record of ozone concentrations and patterns in areas well removed from anthropogenic sources of air pollution and to make these data available to EPA and other interested researchers. All valid data from the NAPBN are

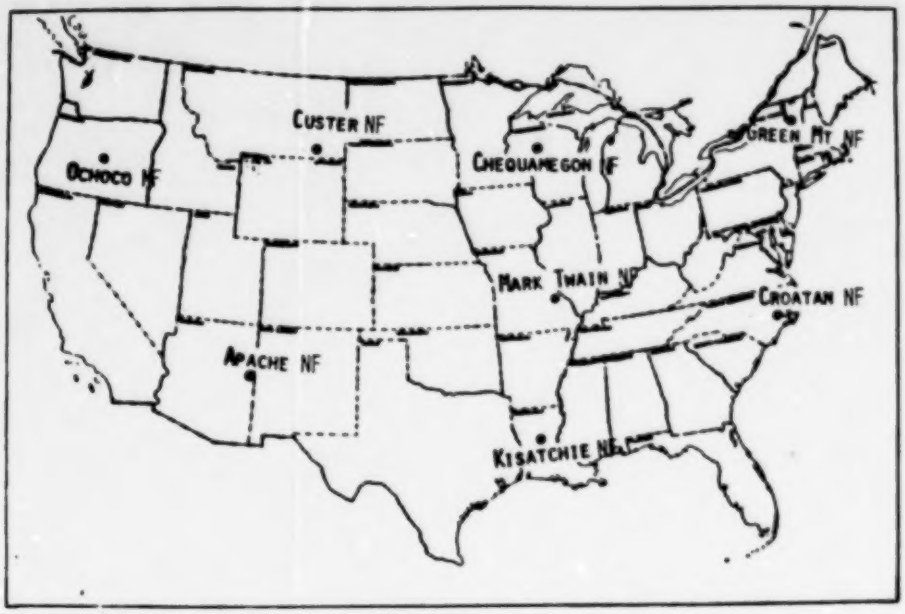


Figure 1. Location of remote ozone monitoring sites.

TABLE 1. DESCRIPTION OF REMOTE OZONE MONITORING SITES

Site	Elevation (msl)	Latitude/ Longitude	Start date
Green Mountain NF VT	390 m	43° 56' 00" N/ 73° 02' 00" W	10/25/76
Kisatchie NF LA	65 m	31° 30' 00" N/ 92° 28' 20" W	5/26/76
Custer NF MT	1250 m	45° 14' 00" N/ 106° 15' 00" W	8/26/76
Chequamegon NF WI	440 m	45° 12' 00" N/ 90° 37' 00" W	8/10/78
Mark Twain NF MO	350 m	37° 28' 00" N/ 90° 11' 00" W	12/09/78
Croatan NF NC	13 m	34° 59' 05" N/ 77° 11' 24" W	3/10/78
Apache NF AZ	2500 m	33° 45' 00" N/ 109° 00' 00" W	9/16/79
Ochoco OR	1350 m	44° 13' 30" N/ 119° 42' 25" W	10/04/79

on file and may be accessed through the National Aerometric Data Bank (NADB) at RTP. In this report, network ozone data are examined, relationships with on-site meteorological measurements are explored, and possible influences from mesoscale air mass movements are investigated.

SECTION 2

CONCLUSIONS

- Although the NAAQS level for ozone (0.12 ppm) was exceeded only once at the NAPBN sites during 1979, high ozone concentrations (>0.08 ppm) did occur, at five of the sites, most frequently during the spring and summer months (April-September).

- With the exception of the Missouri site, the observed concentration distributions of ozone fell within the ranges for ozone of stratospheric origin in remote areas predicted by various researchers.

- Diurnal maximum 1-hour ozone concentrations occurred most frequently in the early afternoon (1-3 p.m.), and the maximum monthly means occurred in the spring (April-June).

- Mean ozone concentration increased with site altitude, and maximum ozone concentrations were greatest in regions having greater density in urban and industrial development.

- Of the three sites which have been operating since 1976, the site at Kisatchie NF, LA, reported slightly lower ozone levels in 1979 and 1980, while the others have shown no detectable trends.

- Regression analyses suggest that local meteorological measurements and seasonality terms can account for just over 50% of the observed variation in ozone concentrations.

- Trajectory analyses indicate that some instances of elevated ozone concentrations (i.e., ozone > 0.08 ppm) may be the result of transport over several hundred miles from distant urban environments.

SECTION 3

BACKGROUND

That some natural background level of ozone exists in the lower troposphere, which is primarily attributable to the exchange of air between the troposphere and the ozone-rich stratosphere, is commonly accepted. Various researchers have postulated what this concentration level might be in the absence of other sources, and how it might vary in time and space. Reiter, (5) for example, has estimated that annual mean tropospheric ozone concentrations of stratospheric origin range from 0.019 to 0.029 ppm. Mohnen (5) has concluded that a range of annual mean concentrations of 0.022 to 0.035 ppm constitutes a representative tropospheric level for ozone of stratospheric origin at mid-latitude locations. Seasonal mean concentrations as high as 0.05 ppm in the boundary layer are believed by Singh, et al, (6) to be the result of stratospheric ozone mixing into the lower levels of the troposphere. This peak in mean ozone concentrations at remote rural areas has been observed during the spring and early summer (7), when stratospheric ozone concentrations over mid-latitudes of the Northern Hemisphere are at a seasonal maximum (8).

The mechanisms that inject stratospheric ozone into the troposphere, including tropospheric folding (TF) events (associated with large-scale atmospheric disturbances) and the mean meridional circulation, have been studied by Danielsen (9), Danielson and Mohnen (10), Reiter (11), and Viezee, et al (12). Although there is still considerable debate on the relative contribution of the two mechanisms, Singh, et al (6) estimate that TF events are responsible for the largest portion of air exchanged between the stratosphere and troposphere. According to Mohnen (5), stratosphere-troposphere interchange processes may cause as many as 0.9% of hourly concentration values at ground level to exceed 0.08 ppm ozone. Although the actual occurrence of stratospheric intrusions reaching the ground have been suggested (13), measurements aloft by Viezee, et al (12) during intrusions associated with TF events indicate that the channel of ozone rich air emanating from the stratosphere becomes horizontal at about 4500 m. Cases of stratospheric air being transported directly to near ground levels are considered rare (6), and are not likely to be responsible for widespread high ozone episodes. The impact of TF events or other exchange mechanisms is probably greatest during the late winter and spring since the strong upper level atmospheric eddies associated with TF events are relatively frequent and most intense in the United States during this season, and the concentration of ozone in the stratosphere is near the annual maximum.

The occurrence of high ozone events during the mid and late summer, however, may not be as closely tied to the stratospheric pool of ozone. Extensive studies have been conducted in rural areas of the Eastern United States (14, 15, 16, 17) to investigate the concentration levels and probable sources of ozone during this season. The highest ozone levels are generally believed to arise from photochemical reactions of anthropogenic emissions which reach rural areas through the direct impact of urban ozone plumes and/or through long-range (multiday) transport of ozone within the lower troposphere (17,18). Photochemical reactions of natural precursor emissions in the troposphere are believed to contribute ozone concentrations of at most 0.03 ppm (19) and typically less than 0.01 ppm (20).

SECTION 4

DESCRIPTIVE ANALYSES

The National Air Pollution Background Network (NAPBN) became fully operational in late 1979 with the establishment of the eighth and final air monitoring station located within the Ochoco NF in Oregon. This section presents an analysis and discussion of the data collected at all sites, including discussions of distributional properties, cyclical patterns, and 5-year histories. Data analysis is concentrated on the year 1979 because fairly complete reduced meteorological records were available for that year. Subsequent sections consider the influence of meteorology on observed ozone concentrations.

DISTRIBUTIONAL PROPERTIES

A cumulative frequency distribution is presented in Table 2 for the ozone data collected during 1979 at each of the eight monitoring sites. Because the sites in Arizona and Oregon were added late in the year (September and October, respectively), the number of hourly measurements available (column 2) is considerably less than for the six sites which were operational for the entire year. Direct comparisons involving these sites is, therefore, of somewhat limited utility.

In 1971, EPA established the first National Ambient Air Quality Standard (21) for photochemical oxidants (primarily ozone) at a 1-hour average of 0.08 ppm, which was not to be exceeded more than once in any given year. Table 2 shows that of the six NAPBN stations operational for the entire year, all but the site at Custer NF in Montana recorded ozone concentrations in 1979 which were in excess of 0.08 ppm. A listing by site and month of these occurrences appears in Table 3. As shown in the table, most hours of elevated ozone concentration (>0.08 ppm) occurred at these sites in the spring and early summer months. Also, a disproportionate share of such instances occurred at the Mark Twain NF in Missouri, where over 2 percent of all hourly averages exceeded 0.08 ppm ozone in 1979.

In 1979, EPA promulgated a revised standard (22), which stated that the expected number of days per calendar year with daily maximum ozone concentrations exceeding 0.12 ppm must be less than or equal to one. This new standard differs from the original in several important ways, including the specific designation of ozone, the emphasis on the daily maximum concentration, and the statistical interpretation of "expected exceedances" (23). The most obvious difference, however, is the change in the level of the standard from 0.08 to 0.12 ppm. This higher concentration level was exceeded in only a single instance in 1979 for the entire eight-site NAPBN. The one exceedance

TABLE 2. CUMULATIVE FREQUENCY DISTRIBUTIONS OF 1979 NAPBN OZONE DATA (PPM)

	YEAR	NUM	MIN	10	30	50	60	70	80	90	95	98	MAX	ARITHMETIC MEAN	ARITHMETIC STD	GEOMETRIC MEAN	GEOMETRIC STD
ARIZONA APACHE NF	79	2427	LD	.035	.045	.050	.050	.055	.055	.060	.065	.070	.080	.0493	.0097	.0482	1.246
LOUISIANA KISATCHIE NF	79	6993	LD	.010	.020	.025	.030	.035	.040	.045	.055	.060	.100	.0269	.0145	.0225	1.916
MISSOURI MARK TWAIN NF	79	8371	LD	.020	.030	.035	.040	.045	.055	.065	.075	.085	.125	.0394	.0181	.0348	1.711
MONTANA CUSTER NF	79	8488	LD	.015	.025	.030	.035	.040	.045	.045	.050	.055	.070	.0315	.0122	.0287	1.594
NORTH CAROLINA CROATAN NF	79	8262	LD	LD	.015	.025	.030	.035	.040	.050	.060	.065	.085	.0279	.0166	.0223	2.087
OREGON OCHOCO NF	79	2096	.010	.020	.025	.030	.030	.035	.035	.040	.040	.040	.050	.0292	.0067	.0284	1.286
VERMONT GREEN MOUNTAIN NF	79	6423	LD	.010	.025	.030	.035	.045	.040	.050	.065	.075	.105	.0317	.0165	.0270	1.860
WISCONSIN CHEQUAMEGON NF	79	7684	LD	.020	.025	.035	.035	.045	.040	.055	.060	.070	.110	.0353	.0148	.0321	1.581

LD: less than .010 ppm

TABLE 3. OCCURRENCES OF CONCENTRATIONS EXCEEDING 0.08 PPM OZONE*

Month	SITE				
	Kisatchie NF	Mark Twain NF	Croatan NF	Green Mt NF	Chequamegon NF
January					
February					
March		1/3		1/2	
April	1/2	5/27		1/4	
May		5/27		1/2	1/9
June		8/45		8/34	8/32
July		7/74		4/17	2/12
August			1/7	1/3	
September		5/24		1/1	
October	1/3	1/3			
November					
December					
Total '79	2/5	32/203	1/7	17/63	11/53
Percent '79	0.1	2.3	0.1	0.7	0.6

* Number of days/hours > 0.08 ppm by site and month for 1979.

(0.125 ppm) occurred at the Mark Twain NF in Missouri on July 21 at 3 p.m. during a week-long episode of elevated ozone levels. The current ozone standard, then, was not technically violated at any of these background sites during 1979.

As may be seen in Table 2, annual arithmetic mean concentrations of ozone at the six sites operated throughout 1979 ranged from 0.027 to 0.039 ppm. This latter value, computed for the Mark Twain NF in Missouri, is the only average to exceed the range predicted by Mohnen (5) for ozone of stratospheric origin. Also, as shown in the last row of Table 3, the Mark Twain NF was the only site to record a higher frequency of concentrations exceeding 0.08 ppm ozone than the 0.9% suggested by Mohnen. This southeastern Missouri site, then, seems to reflect some contributor(s) to ozone concentrations beyond the natural background expected from the stratospheric source.

CYCLICAL PATTERNS

Average 1979 ozone concentrations by hour-of-day in local standard time are shown on a quarterly basis in Figure 2. Values plotted are a composite of the six sites operating throughout 1979 (i.e., all except the Arizona and Oregon sites) since these sites exhibited very similar diurnal and seasonal patterns. Ozone concentrations typically began to build at about 7 a.m., reached a maximum shortly after the noon hour, and then declined throughout the evening and early morning hours. The average levels were highest in the second quarter (April through June), with a small decrease in the third quarter (July through September), and with relatively low average levels prevailing for the remainder of the year.

The individual hourly data were divided into weekdays (Monday through Friday) and weekends (Saturday and Sunday) and statistically tested for any significant differences. None were found, suggesting that ozone concentrations at these locations contain little or no weekday-weekend pattern.

Overall monthly average ozone concentrations for the 1979 6-site composite data set are plotted in Figure 3. Again, the seasonal cycle is essentially quadratic with the annual peak occurring in the second quarter months of April, May, and June. This pattern conforms to the expected behavior of background ozone of stratospheric origin as previously discussed in Section 3.

The cyclical patterns observed at the remote locations of the NAPBN differ notably from the patterns characteristic of monitoring sites in urban or suburban locations. Typically, ozone concentrations are negligible during the evening and early morning hours, the seasonal mean concentrations are greatest in the summer and early fall months, and concentrations observed on weekdays generally exceed those observed on weekends.

FIVE-YEAR HISTORIES

The ozone data from the NAPBN sites established in 1976 (i.e., those in Louisiana, Montana, and Vermont) are summarized in Table 4. The summary lists by site and year the number of valid hourly ozone values, the data

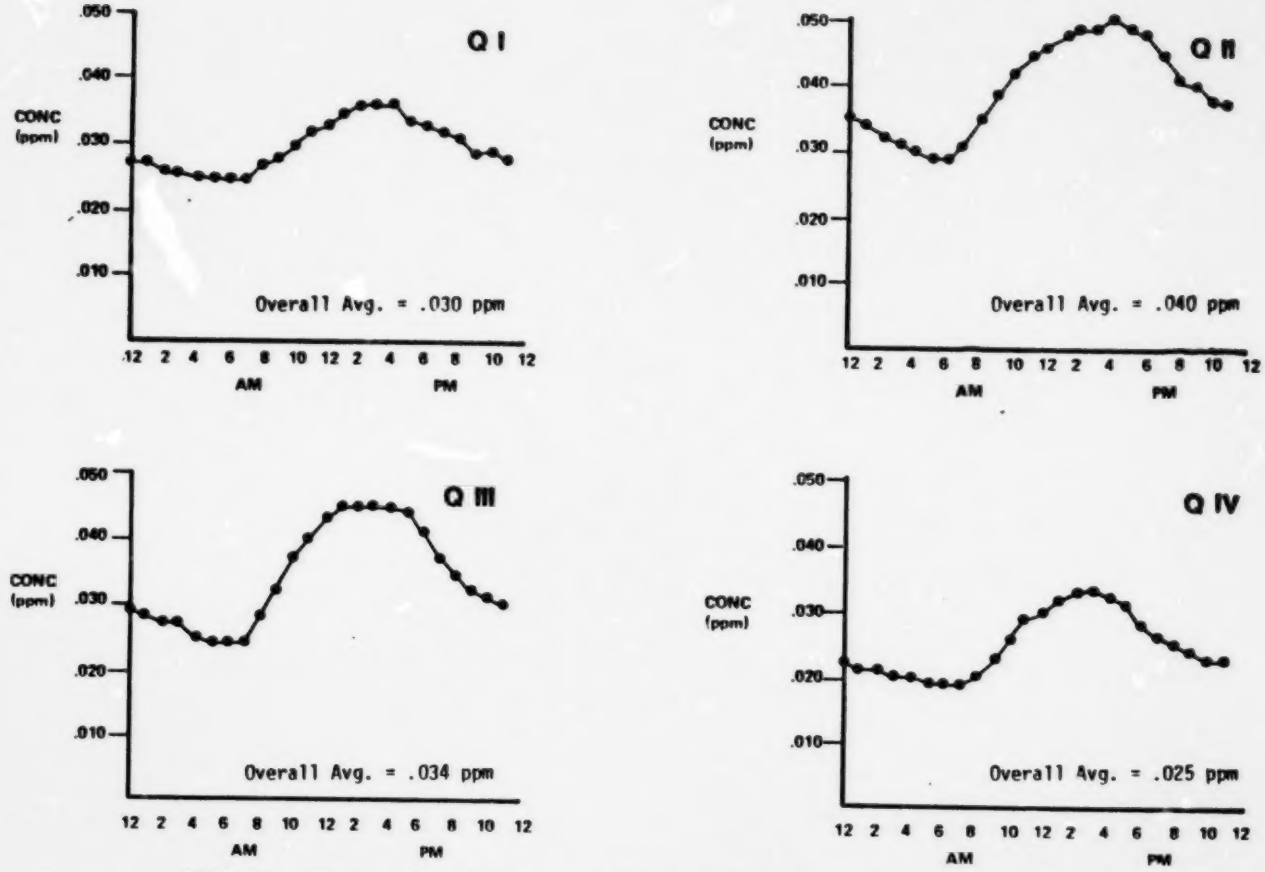


Figure 2. Diurnal plots of 1979 ozone data by quarter (6 sites).

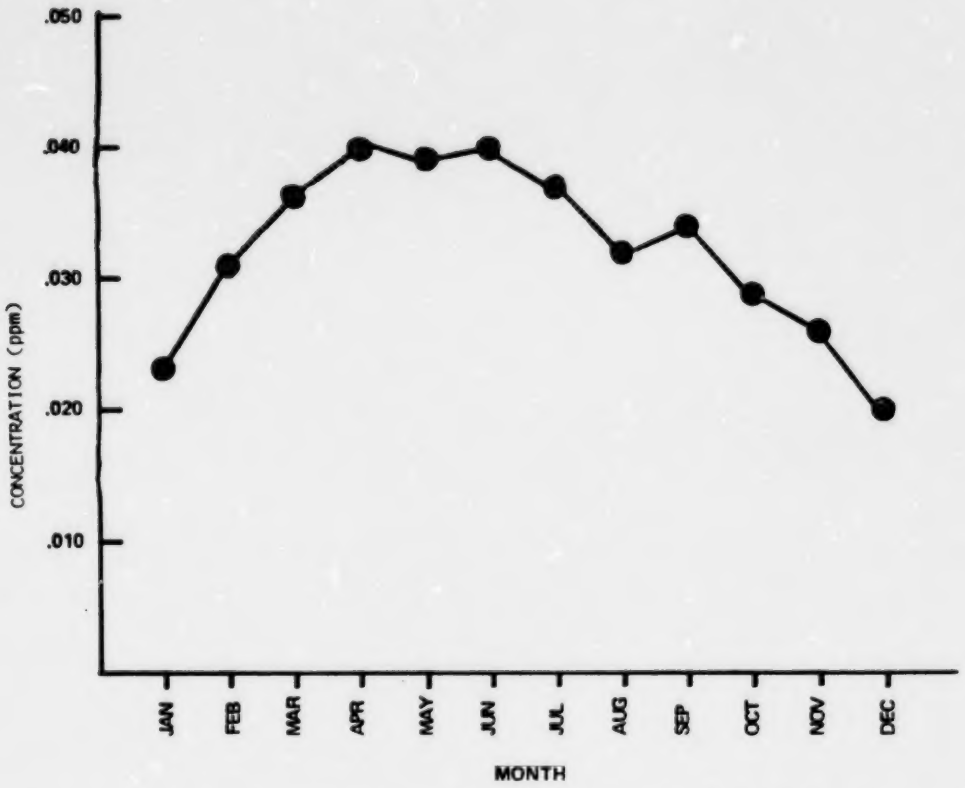


Figure 3. Monthly average ozone concentrations for 1979 (6 sites).

TABLE 4. ANNUAL OZONE SUMMARY STATISTICS (PPM)

Site	Year	No. Obs.	% Data	Min.	Arithmetic Mean	Arithmetic Std.	Geometric Mean	Geometric Std.	Max.
Kisatchie NF, LA	76	3448	39.4	LD	0.032	0.021	0.024	2.19	0.125
	77	6793	77.5	LD	0.033	0.023	0.025	2.25	0.135
	78	5636	64.3	LD	0.034	0.021	0.027	2.14	0.125
	79	6993	79.8	LD	0.027	0.015	0.023	1.92	0.100
	80	4438	50.7	LD	0.028	0.016	0.023	1.94	0.105
Custer NF, MT	76	275	3.1	0.020	0.039	0.008	0.038	1.22	0.060
	77	7603	86.8	LD	0.040	0.011	0.039	1.37	0.080
	78	7674	87.6	LD	0.030	0.017	0.023	2.14	0.075
	79	8488	96.9	LD	0.032	0.012	0.029	1.59	0.070
	80	7754	88.5	LD	0.037	0.012	0.035	1.41	0.070
Green Mt. NF, VT	76	1058	12.1	LD	0.029	0.011	0.026	1.76	0.060
	77	6483	74.0	LD	0.038	0.021	0.031	2.00	0.145
	78	3671	41.9	LD	0.029	0.018	0.024	2.01	0.105
	79	6423	73.3	LD	0.032	0.017	0.027	1.86	0.105
	80	8574	97.9	LD	0.032	0.017	0.027	1.90	0.115

capture rate as a percentage of all possible hours, the minimum and maximum hourly ozone concentrations, and the arithmetic and geometric means and standard deviations.

The sites became operational at various times during 1976 so the record for that year is quite incomplete. Nonetheless, there is some indication of long-term trend at the Louisiana site where both the mean and maximum ozone values were lower in 1979 and 1980 than in the first three years of site operation. No clear trends appear in the data from Montana and Vermont.

SECTION 5

MULTIVARIATE ANALYSIS

In addition to ozone concentration measurements, hourly measurements were made of wind direction, wind speed, temperature, relative humidity, and solar radiation occurring at each of the NAPBN monitoring locations. This section attempts to relate the 1979 NAPBN ozone data to the concomitant meteorological conditions recorded at the sites. These relationships are examined by regression analyses, cluster analyses, and regression analyses within clusters. The final section of the report considers air parcel paths which are associated with the highest ozone levels observed at NAPBN sites.

REGRESSION ANALYSES

To determine to what extent local meteorological conditions may be used to predict ozone concentrations in remote areas, linear models were constructed using the 1979 NAPBN data. Ozone, the dependent variable, was modeled as an additive function of the independent meteorological variables. Since the records of meteorological variables at each site had sizeable gaps, linear modeling by multiple stepwise regression involved decisions about which data to include, whether or not to fill in for missing data, and how to handle seasonal trends. As standard procedures, the decisions were: (1) to exclude some days in 1979 if necessary to retain a meteorological variable in the model, (2) to avoid filling in data because of the often lengthy periods of missing data, and (3) to convert data values to departures from a monthly or seasonal mean value whenever possible to minimize seasonal trend effects.

Considering each of the measured variables individually, average ozone concentration from 1300-1800 hours local time as the dependent variable (Y) in ppm showed the expected large seasonal cycle in the residuals, i.e., predicted minus measured values. There were large positive residuals in spring and early summer, and negative residuals in fall and winter at the sites examined.

Because of the lack of mean ozone values obtained over a suitably long period, departures could not be computed. Therefore, a time variable (M) was introduced in the form of the month number, and a second time variable was added in the form of the square of the month number (MSQ). Thus for December, M = 12 and MSQ = 144. The discontinuity in this variable between years did not matter when treating only one year's data.

Wind direction (V_d) also presented a discontinuity, this one occurring at 360°. The effect was studied by rotating the zero point on the compass scale to other locations. Again, the discontinuity was found acceptable as it stood, so wind direction became an independent variable along with wind speed (V_s) in mi/hr and relative humidity (H) in %. In troublesome cases, the discontinuity in wind direction would be avoided by converting V_d and V_s to wind components.

Solar radiation has a large seasonal fluctuation, so climatic information (24) from neighboring National Weather Service sites was used to establish mean daily values by month. The departure (δR) in Langleys from the mean daily value became the variable representing this parameter.

Temperature was handled in the same manner as solar radiation, resulting in a departure (δT) in °C as a seventh independent variable. This completed the set of NAPBN variables, but since air pressure data were available from neighboring National Weather Service sites, it was thought useful to include it as another independent variable. A mean daily air pressure value was computed for each season and the departure (δP) in inches Hg from the mean daily value became the eighth independent variable. For conciseness, the three departure variables were labeled delta solar radiation, delta temperature, and delta pressure.

The residuals for Croatan NF, NC, a site with all variables except relative humidity, are shown in Figure 4. They indicate symmetry around the zero line. However, there is some correlation with time in all seasons and more variability in summer than in other seasons. Such transgressions from the usual assumptions for regression are fairly common at all sites, but this handicap is offset somewhat by the robustness of the regression method.

A summary of explained variance in ozone concentration (R^2) for the six sites is given in Table 5, with a breakdown into two categories: "meteorological variables" and "time variables." The regression program used was the Biomedical Computer Programs P-Series (25) stepwise regression package. Interaction among the variables was neglected. An inspection of this table reveals an R^2 of about 0.50 for the combined variables, excepting Custer NF with its 0.82 due largely to contributions from M and MSQ, and Mark Twain NF with an R^2 of 0.26. Kisatchie NF is the only site that exceeded 0.50 for the meteorological variables. This site most likely exceeded 0.50 because of the strong negative correlation between relative humidity and ozone concentration there.

Attempts to combine the sites decreased the R^2 values to the 0.30 to 0.37 range. However, confining the analysis to only the April to June period allowed the time variables to be dropped and increased the R^2 by a tenth.

In summary, linear modeling by sites and by a combination of sites produced a substantial number of significant variables in the stepwise regression procedure, but the amount of the variance ascribed to meteorological variables was consistently small.

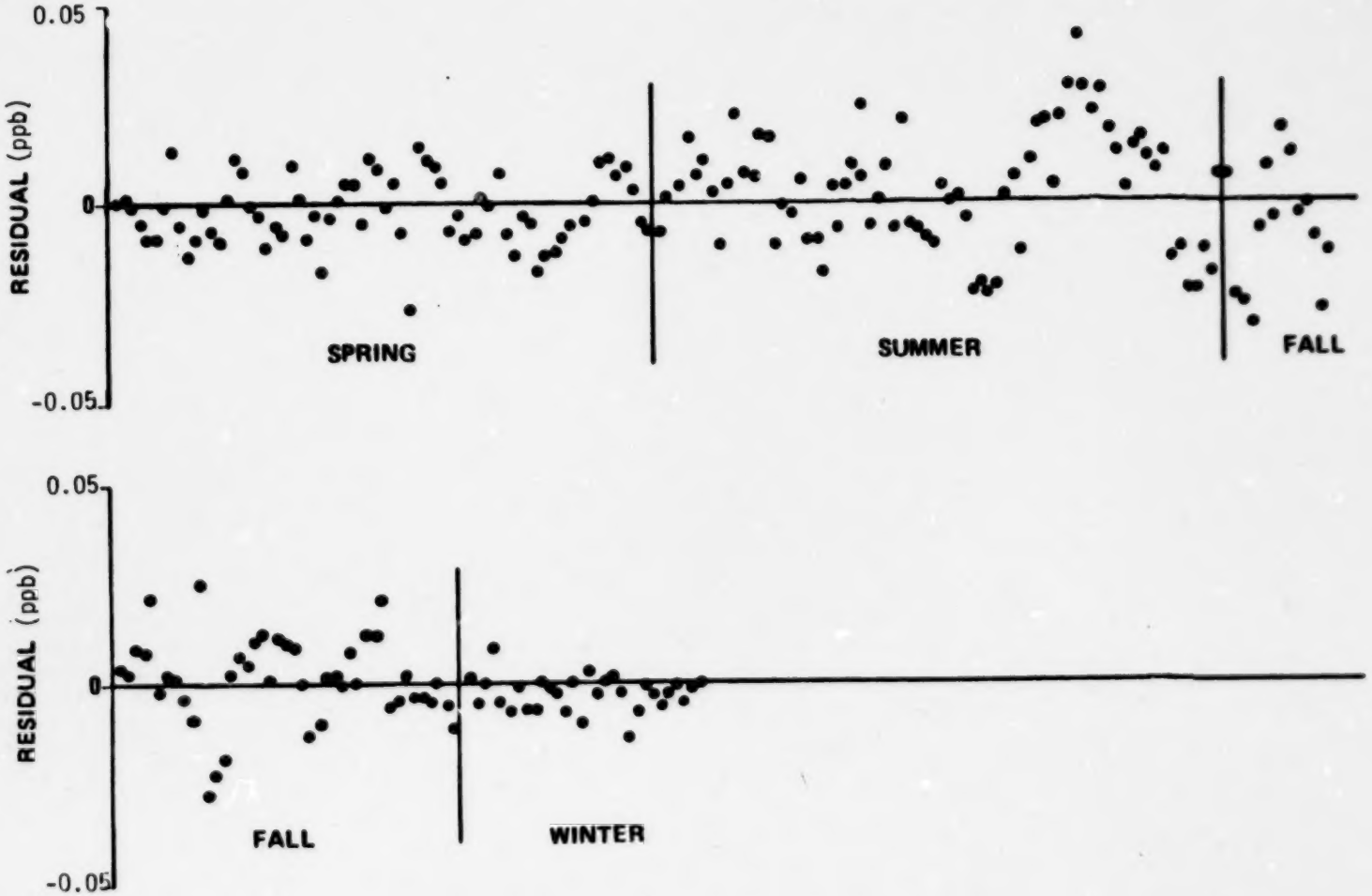


Figure 4. Croatan National Forest ozone residuals for 1979.

TABLE 5. STEPWISE REGRESSION ANALYSIS FOR 1979 NAPBN OZONE DATA

	Number Days	Independent Variables*	R^2 Meteorological Variables	R^2 Time Variables	R^2 Combined
Chequamegon, WI	218	all	0.319	0.211	0.530
Croatan, NC	228	all but H	0.158	0.316	0.474
Custer, MT	57	all	0.075	0.740	0.815
Green Mountain, VT	185	all but H	0.155	0.410	0.565
Kisatchie, LA	65	all but δT	0.515	0.137	0.652
Mark Twain, MO	104	all but H, δT	0.153	0.105	0.258

*These include the meteorological variables: wind direction (V_d), wind speed (V_s), delta solar radiation (R), delta temperature (T), relative humidity (H), and delta pressure (P), and the time variables: month number (M) and month number squared (MSQ).

CLUSTER ANALYSES

The approach to cluster analysis assumes that the sample analyzed is drawn from a population that is actually a mixture of distributions of known forms but unknown parameters. By repeated computation of spatial distances in n-space among sample points, separation into groups is sought with its associated estimation of parameters and tests of hypotheses. Cluster parameters, in turn, can provide pertinent information regarding the physical processes that affect ozone levels.

The form of a multivariate distribution determines what statistical analysis procedure is optimal in leading to insights about the relationships among variables. For example, Crutcher and Joiner (26) point out that linear multivariate regression techniques are applicable to unimodal, normally distributed variables, but not to multimodal variables. Conversely, separation into significant clusters can be accomplished with multimodal, but not unimodal, distributions. However, regression can be performed on individual clusters, provided that complete clustering is achieved. Therefore, the strategy of the present investigation will be to attempt clustering and then do stepwise regression within each cluster whenever it is permissible.

The Wolfe NORMIX clustering algorithm (27) was selected to group the data. This program uses an hierarchical procedure to form preliminary estimates of cluster membership and of the parameters, and then uses a maximum likelihood method to obtain descriptive statistics for each cluster and also cluster membership probabilities. Each proposed increase in the number of clusters must survive a significance test based upon the chi-square asymptotic distribution of 2 log λ, where λ is the ratio of maximum

likelihood estimates for the observations. Several options added to the program are described by Rhodes, et al (28).

The separation of the data for each site into significant clusters is shown in Table 6. Column 1 of this table indicates the variables which had sufficient data in 1979 to be included in the study. Column 2 gives the overall regression result with a list of independent variables entering the functional expression that is generated, and cumulated explained variance, R^2. Additional columns give the number of points (N) in each cluster and other information similar to that of Column 2. A maximum of six significant clusters is permitted.

Examination of means within clusters usually reveals the basis for separation into clusters. For example, the Profile Chart (28) for three clusters at Chequamegon NF in Wisconsin (Figure 5) exhibits the departures from overall means for each cluster variable. In the case of ozone, transformation to natural logarithms makes the mean a geometric mean, or median. The variables have been ordered so that the cluster with the largest proportion, namely, 0.453, is represented by a continuous, rising curve. The pairs of diamond symbols above and below the rising curve are 2-sigma deviations from the cluster means for each variable. The horizontal lines at the top and bottom are 3-sigma limits in original units for the entire data set of 218 observations, the lower limit often being negative and not meaningful because the distribution is bounded by zero. Corresponding symbols for the other clusters are easily read from the diagram.

Proceeding across the Profile Chart, the continuous curve for the largest proportion shows a large negative departure from the mean for relative humidity, small north and east components of wind, and positive departures for delta pressure, delta temperature, ozone, and delta solar radiation. The dashed curve representing a proportion of 0.339 in its cluster has a positive departure in relative humidity, southerly and westerly wind components, and negative departures roughly matching those of the continuous curve in magnitude. The remaining curve also shows a positive bias in relative humidity, northerly and westerly wind components, as well as small negative biases for delta temperature, ozone, and delta solar radiation.

Thus, the plotting of variable profiles such as these for Chequamegon NF displays differences in cluster means that are often indicative of physical causes for the separation of the data set into significant groups.

A second mode of representation is the Probability Ellipse (26) that gives two-dimensional projections of n-dimensional data on a selected pair of axes. Such an ellipse has an attached probability, so that it encases a corresponding fraction of points in a cluster when the cluster has a normal distribution. Its location is determined by the centroid, the orientation of the major axis is determined by the variances and covariances of the two variables, and the lengths of the major and minor axes depend upon the eigenvalues of the covariance matrix.

TABLE 6. CLUSTER ANALYSIS AND STEPWISE REGRESSION ANALYSIS WITHIN CLUSTERS*

		Overall		Cluster Number 1		2		3		4		5	6
Site and Variates	N	Variable	R^2	N	Variable R^2	N	Variable R^2	N	Variable R^2	N	Variable R^2	N	N
Cheqamegon NF	218	δT	0.220	42		12		62		44		29	29
*O_3, δR, V_s, V_d,		MSQ	0.391										
		M	0.472										
M, δT, δP, M, MSQ		M	0.512										
		V_s	0.530										
Croatan NF	228	MSQ	0.316	29		57		49		55		22	16
		δR	0.441										
O_3, δR, V_s, V_d,		δT	0.461										
		V_s	0.474										
δT, δP, M, MSQ													
Custer NF	57	M	0.713	16	MSQ 0.557	33	M 0.605	3	V_d 0.918	5	M 0.816		
		δR	0.788				δP 0.736						
O_3, δR, V_s, V_d,		MSQ	0.815										
M, δT, δP, M, MSQ													
Green Mountain NF	85	MSQ	0.136	39		30		19		53		44	
		M	0.410										
O_3, δR, V_s, V_d,		δT	0.482										
		δR	0.530										
δT, δP, M, MSQ		δP	0.547										
		V_s	0.565										
Mark Twain NF	104	δR	0.153										
		M	0.209										
O_3, δR, V_s, V_d,		MSQ	0.258										
δP, M, MSQ													

*The dependent variate is ozone (O_3).

The independent variates are delta solar radiation (δR), wind speed (V_s), wind direction (V_d), relative humidity (M), delta temperature (δT), delta pressure (δP), month number (M), and month number squared (MSQ).

The F-test critical values used to enter or remove a variate are the default values of 4.0 and 3.9, respectively.

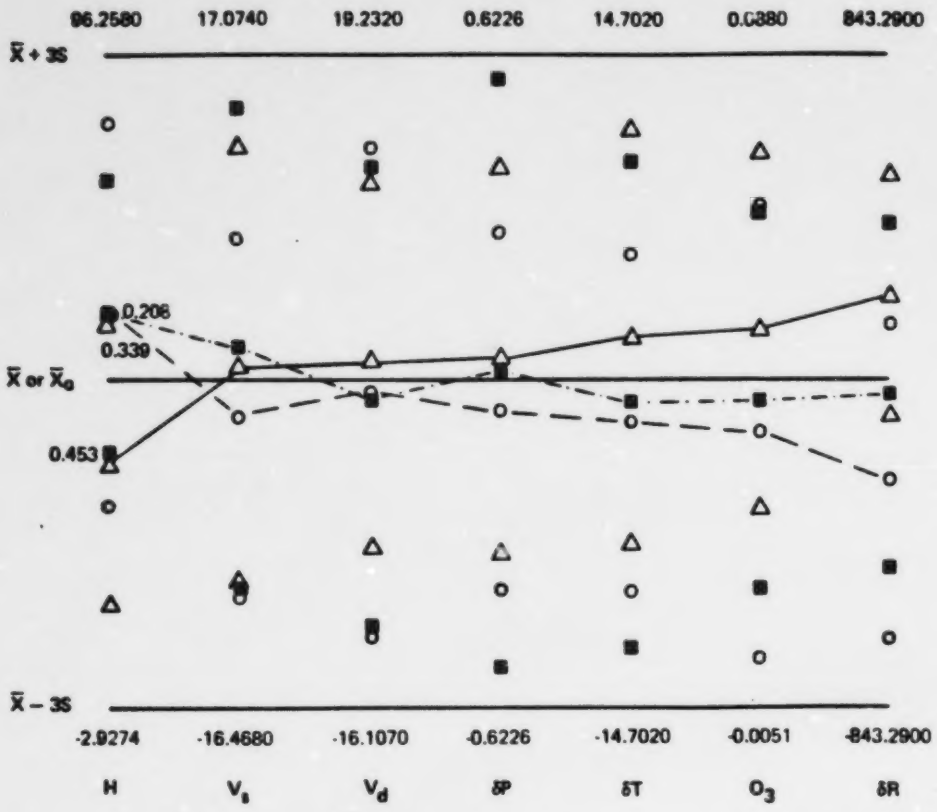


Figure 5. Cluster Profile Chart for Chequamegon National Forest.

A display of 0.50 Probability Ellipses for five clusters at Green Mountain NF, Vermont, is presented in Figure 6. A box is provided in Figure 6 giving the statistics for the six variables. Below the box, ellipses are drawn for a selection of two of the variates: log ozone and delta temperature. The mean values of these variables are represented by perpendicular lines on the diagram.

Although much overlapping in two dimensions is apparent in these curves, the large oval-shaped ellipse in the upper left quadrant is rather well separated. This ellipse is characterized by low ozone levels, i.e., strongly negative logarithms of ozone, and high temperatures. It obviously corresponds to Cluster No. 1 in the box, and has a proportion (P) of 0.205 of the entire data set. The flat ellipse below it also has low ozone levels but relatively low temperatures; it is Cluster No. 3 in the box with a proportion of 0.103. Some elongation is evident in two of the other clusters, the extension being in the direction of high ozone levels and high temperatures. Such a relationship is found to be pronounced at Green Mountain during June 1979, and it is examined in more detail in Section 6.

GREEN MT. - ORIGINAL OZONE					
	CLUSTER N = 185				
VARIABLE	1	2	3	4	5
OZONE	P= .205	P= .163	P= .103	P= .281	P= .249
MEAN	-3.69	-3.08	-3.65	-3.29	-3.23
STANDARD DEVIATION	0.39	0.29	0.29	0.21	0.31
SOLAR RAD. ANOMALY					
MEAN	-30.96	326.92	185.51	57.39	-328.8
STANDARD DEVIATION	77.99	83.83	95.79	228.95	212.63
WEST COMP					
MEAN	0.31	1.08	0.54	2.19	-0.82
STANDARD DEVIATION	3.42	2.37	1.72	1.72	2.75
SOUTH COMP					
MEAN	1.73	0.14	1.12	-3.56	2.19
STANDARD DEVIATION	3.32	3.32	2.86	2.10	2.92
TEMPERATURE ANOMALY					
MEAN	4.41	0.71	-6.54	-1.97	0.83
STANDARD DEVIATION	5.56	6.00	3.08	5.75	7.12
PRESSURE ANOMALY					
MEAN	-0.22	0.09	0.31	-0.01	0.02
STANDARD DEVIATION	0.32	0.12	0.22	0.22	0.20

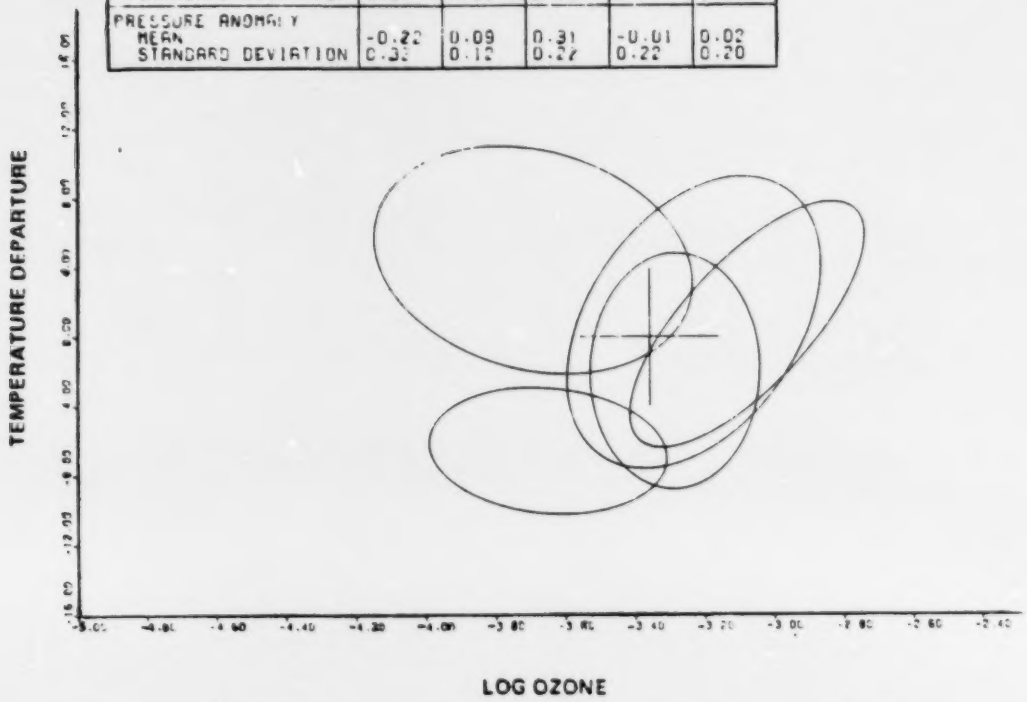


Figure 6. Probability Ellipse for Green Mountain National Forest.

REGRESSION WITHIN CLUSTERS

Linear regression within clusters is permitted when there is complete separation. In this study, complete separation occurred only in the Custer NF data, which show little input from the meteorological variables to the linear modeling of the entire data set (Table 5). However, in Cluster No. 2, relative humidity and delta pressure account for 0.736 of the variance in ozone. Clusters Nos. 3 and 4 have still greater R^2, but they have but 3 and 5 members, respectively. Nevertheless, these are significant clusters

that may have important information in their parameters. The regression coefficients for Custer NF are displayed in Table 7.

In analyzing the 1979 data, the overall performance of site temperature as a predictor of ozone level was not very impressive in the cases of the NAPBN sites. For example, in Table 6, data from all seasons reveal at best a weak relationship between the two variables; e.g., at Chequamegon δT explains but 22% of the variance in ozone. On the other hand, when treating a limited portion of the year as in the trajectory analyses to follow (see Section 6), the association between these two variables is often very striking.

There is a precedent for finding such a relationship, as was noted in the report by SRI International and Colorado State University (29). That study of a northeastern U.S. region reported an increase of rural ozone formation with high temperature, and further reported as strong a statistical relationship between ozone and temperature as could be established between ozone and any optimized combination of other meteorological parameters.

A possible physical explanation for this relationship may lie in the increased photochemical production of ozone from its precursors at temperatures above a threshold value. Greater convective activity on hot days may undergird the production aspect by carrying ozone downward from altitudes of higher concentration to the site of the measuring instrument. On the other hand, temperature is a surrogate measure for other meteorological systems and events such as stationary high pressure systems and strong southerly flow. A complete physical explanation is not yet available.

In conclusion, the successful grouping of multivariate observations at most sites indicates multimodality and is consistent with the lack of success in linear modeling. The wide range of ozone concentrations during the year at all sites tends to swamp the short-period fluctuations of meteorological variables, but in modeling results improve some when the period of investigation is confined to the spring and early summer ozone season. In Section 6, the consideration of concomitant observations at a site will be supplemented by the study of meteorological synoptic-scale features and the back trajectories of air parcels undergoing important changes prior to arrival at the site.

TABLE 7. STEPWISE REGRESSION COEFFICIENTS FOR CUSTER NF OVERALL AND WITHIN CLUSTERS

		Cluster #1				Cluster #2				Cluster #3				Cluster #4			
Site and Variates	n	Variables Retained	b_1	b_0*	n	Variables Retained	b_1	b_0	n	Variables Retained	b_1	b_0	n	Variables Retained	b_1	b_0	n	Variables Retained	b_1	b_0
Custer, MT	57	H	0.0094	0.0046	16	MSQ	0.0012	0.0143	33	H	-0.0005	0.0756	3	Y_d	-0.0016	0.5319	5	H	-0.0007	0.0683
		H	0.0000***							P	0.0207	0.0349								
O_3, R, Y_L, Y_d, H, T, P, W, MSQ		MSQ	-0.0005																	

*b_0 is the Y-intercept

***The software package prints just 4 places to the right of the decimal point

SECTION 6

OZONE CASE STUDIES

To examine the possibility of transport as an important contribution to ozone at the NAPBN sites, synoptic-scale trajectory analyses were conducted for selected cases (days) of measured high ozone concentrations. For this analysis, 1979 ozone measurements at the NAPBN sites were first screened to identify days with high and low ozone concentrations. A high ozone day at a particular site was defined as a day when at least one hourly average ozone concentration exceeded 0.08 ppm. The number of such days for each site is listed by month in Table 8. These data indicate that the number of high ozone cases varied considerably from site to site.

TABLE 8. NUMBER OF DAYS AT NAPBN SITES WHEN OZONE EXCEEDED 0.08 PPM (0800-2300)

Site	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Green Mt. NF	0	0	1	1	1	7	3	1	-	-	-	0	14
Kisatchie NF	0	0	0	1	0	0	-	0	0	1	0	0	2
Mark Twain NF	0	0	1	4	4	9	6	0	5	0	0	0	29
Chequamegon NF	0	0	0	0	1	4	2	0	0	0	0	0	7
Croatan NF	0	0	0	0	0	0	0	1	0	0	0	0	1
Custer NF	NO OCCURRENCES												0
Ochoco NF	-	-	-	-	-	-	-	-	-	0	0	0	0
Apache NF	-	-	-	-	-	-	-	-	-	0	0	0	0

The lack of high ozone cases at Apache NF and Ochoco NF cannot be meaningfully compared to the incidence of cases at the other sites, since these two did not begin operating until the latter part of 1979. Of the remaining six sites, Mark Twain NF had, by far, the greatest number of high ozone days. An explanation for the distribution of high ozone cases among the sites has not been found, but that such a difference exists implies some uniqueness in background ozone between the regions represented by each of the sites. Therefore, the need for a network of sites for assessing the variability in background ozone concentrations is apparent.

The distribution of high ozone days by month indicates that most of the cases occurred during the June-September period when the potential for photochemical formation of ozone in the boundary layer (lower troposphere) was greatest. However, high ozone was measured, on occasion, during the spring at Mark Twain, Chequamegon, Kisatchie, and Green Mountain National Forests. The seasonal pattern in ozone observed at the NAPBN sites is tied to the types of sources contributing to background ozone concentrations as discussed in Section 3. At Mark Twain, Green Mountain and Chequamegon National Forests,

the cases examined were chosen at random from the subgroup of high ozone days occurring during the period June through September. At Kisatchie NF, the April case was selected, and at Croatan NF the single case in August was analyzed.

To establish a comparison with high ozone days, a number of other (low ozone) days were selected from the period April through June 1979 for the sites in Missouri, Vermont, Louisiana, and Wisconsin. These days, listed in Table 9, were then examined in the same manner as the high ozone cases. The mean daily 1-hour maximum and the highest 1-hour ozone concentration for each period are also shown in Table 9.

TABLE 9. LOW OZONE PERIODS

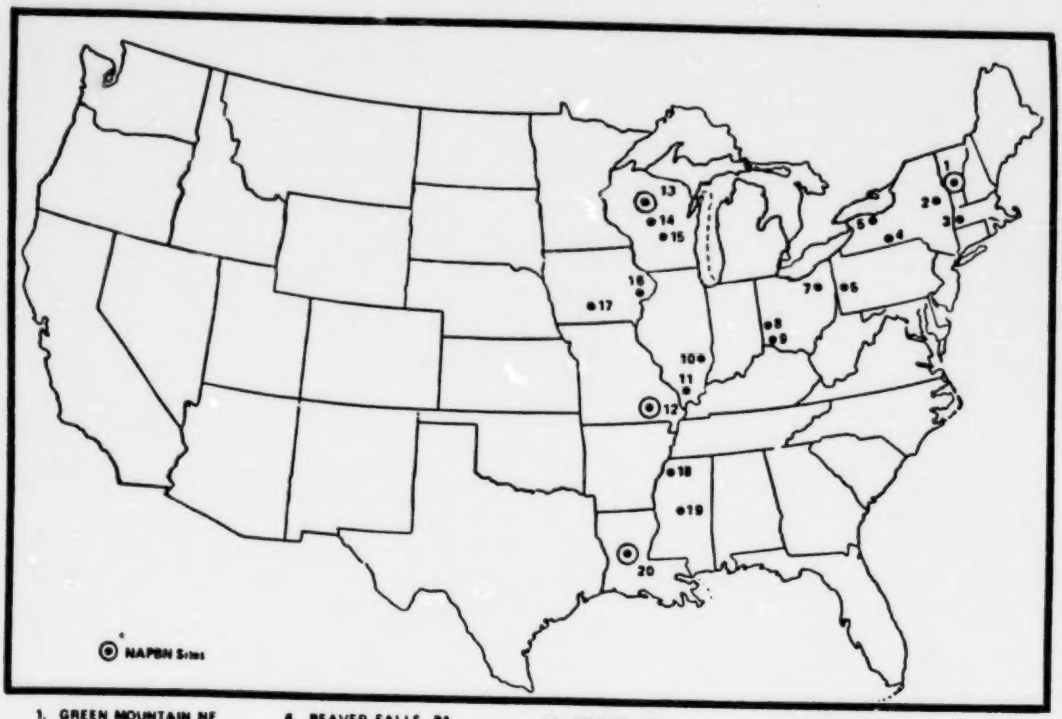
Site	Period (1979)	Ozone Concentration (ppm) Mean Dail Max.	Period Max
Mark Twain NF, MO	April 22-30	0.056	0.065
	June 6-10	0.048	0.055
Green Mt. NF, VT	June 11-14	0.040	0 060
	June 23-26	0.035	0.040
Kisatchie NF, LA	April 20-28	0.040	0.060
Chequamegon NF, WI	May 12-15	0.058	0.060
	June 21-23	0.040	0.045

The synoptic-scale back trajectories used to examine ozone transport were computed from the Air Resources Laboratories Atmospheric Transport and Dispersion Model (ATAD) described by Heffter (30). For computing trajectories, upper-air winds were averaged within a 400 m layer centered on 1000 m AGL. Plots of the trajectories are provided for the days in each case study period, beginning (backward in time) from the NAPBN sites at the local times indicated. The trajectory segments are marked in 12-hour increments. In addition to the data from NAPBN sites, ozone data from other rural monitoring sites operated by state and/or local agencies were included in the analyses. The locations of these sites are shown in Figure 7. The following discussions describe the trajectories and synoptic-scale meteorological conditions associated with the high ozone cases.

HIGH OZONE PERIODS

Mark Twain NF -- Case Study: July 17-24, 1979

The daily 1-hour maximum ozone concentrations for the case study period at Mark NF Twain and four other rural Midwest sites are shown in Figure 8. The pattern indicates a rise in ozone concentration to peak levels on July 20



1. GREEN MOUNTAIN NF
2. GLEN FALLS NY
3. PITTSFIELD MA
4. ELMIRA NY
5. MONROE NY
6. BEAVER FALLS PA
7. PORTAGE OH
8. PREBLE OH
9. HAMILTON OH
10. ROBINSON IL
11. MARION IL
12. MARK TWAIN NF
13. CHEQUAMEGON NF
14. JUNEAU WI
15. COLUMBIA WI
16. SCOTT IA
17. MADISON IA
18. DeSOTO MS
19. MADISON MS
20. KISATCHIE NF

Figure 7. Location of rural ozone monitoring stations.

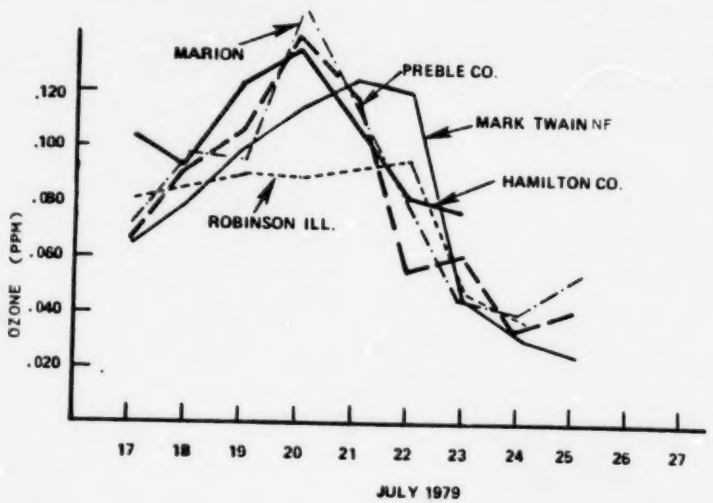


Figure 8. Daily maximum 1-hour ozone concentration (0800-2300) July 17-25, 1979.

and 21, followed by a rapid decrease on July 22 and 23. The dominant synoptic-scale meteorological feature in the Midwest during this period was a large high pressure system that traversed the region from west to east. The center of the high moved to the north of the Mark Twain NF site on July 19, then weakened considerably as it neared the East Coast on the following day.

From July 17 through July 21 (the period of increasing ozone concentration), there were clear skies in the Midwest in association with the high pressure system, with maximum temperatures in the mid-80's (°F). Thus, meteorological conditions during this period were favorable for ozone formation from anthropogenic sources. An area of low pressure, which formed over the Tennessee Valley on July 22, spread clouds and rain into the lower Midwest, diminishing photochemical activity by July 23.

Figures 9a-g display the trajectories outlined during the case study. On July 17, the air passing the Mark Twain NF site had crossed predominantly rural areas 36 hours earlier, and low ozone concentrations were observed. Beginning on July 18, the air parcel paths crossed major urban centers prior to reaching the Mark Twain NF site. Specifically, the Chicago-Gary area was 24-36 hours upwind on July 18 and 19. On the 20th, the trajectories passed in the vicinity of Detroit, 72 hours upwind from Mark Twain NF, and then followed the Ohio River Valley, passing near Cincinnati (36 hours upwind). Emissions from St. Louis appear to have had an impact on the 21st and 22nd, when the trajectory paths indicated that the site was directly downwind of the St. Louis area. On the final day in the series, the trajectories arrived from the south and east, with Memphis being the only urban area upwind within 48 hours. However, as previously indicated, meteorological conditions were unfavorable for ozone formation.

The relatively high ozone concentrations at the other rural sites indicate that the episode was rather widespread. In particular, on July 20 and 21, the sites along the trajectories that crossed several urban areas measured ozone exceeding 0.12 ppm. Variability in absolute concentrations between the sites is likely because of the differences in the travel time and actual parcel paths from urban areas to the individual sites.

Green Mountain NF -- Case Study: June 13-19

The daily maximum 1-hour ozone concentrations at Green Mountain NF and at other rural sites in the vicinity and upwind during the case study are shown in Figure 10. At the start of this period, a high pressure system that had been slowly moving into the Northeastern U.S. from Canada was centered over New Jersey. Mostly clear skies were associated with this system, and daily maximum temperatures in the Midwest and Northeast increased from the low 70's (°F) on June 14 to the upper 80's (°F) by June 17. Meteorological conditions during the period became increasingly favorable for photochemical production of ozone from anthropogenic emissions. Surface winds from the south to southwest occurred across much of the Midwest and Northeast as the high pressure system weakened and drifted off the East Coast.

Figure 9a. Trajectory analysis plots at Mark Twain National Forest, MO: July 17, 1979.

Figure 9b. Trajectory analysis plots at Mark Twain National Forest, MO: July 18, 1979.

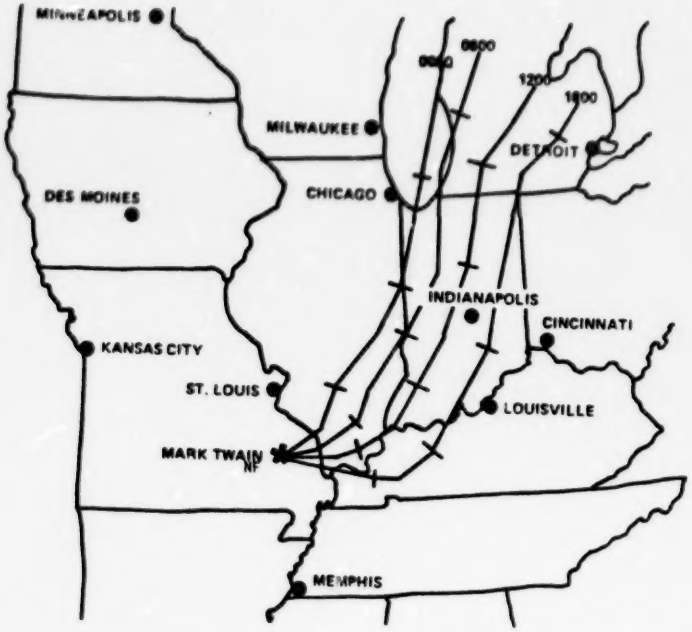


Figure 9c. Trajectory analysis plots at Mark Twain National Forest, MO: July 19, 1979.

Figure 9d. Trajectory analysis plots at Mark Twain National Forest, MO: July 20, 1979.

Figure 9e. Trajectory analysis plots at Mark Twain National Forest, MO: July 21, 1979.

Figure 9f. Trajectory analysis plots at Mark Twain National Forest, MO: July 22, 1979.

Figure 9. Trajectory analysis plots at Mark Twain National Forest, MO: July 23, 1979.

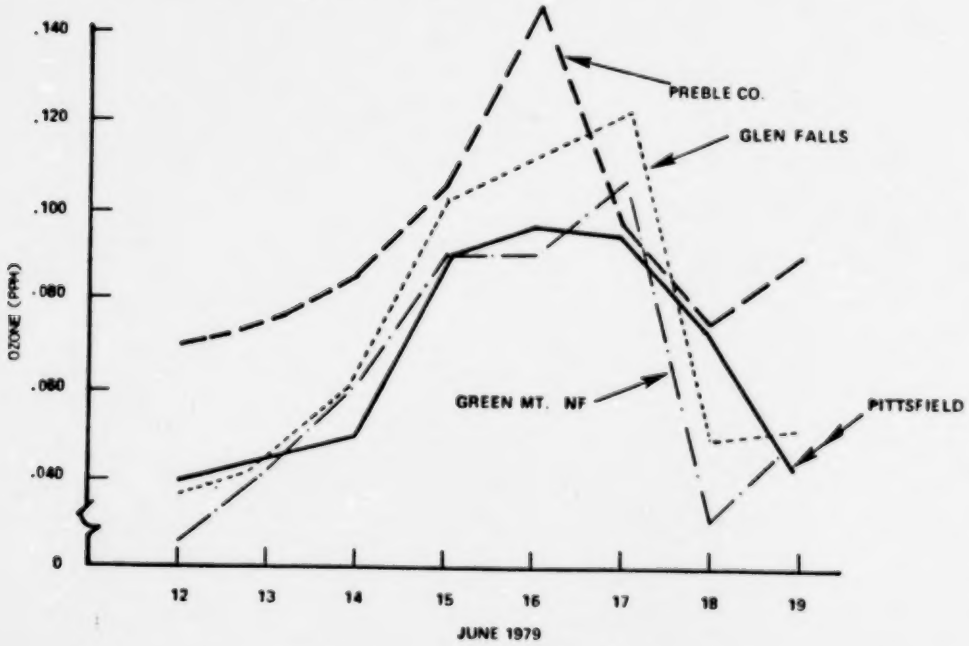


Figure 10. Daily maximum 1-hour ozone concentration (0800-2300): June 12-19, 1979.

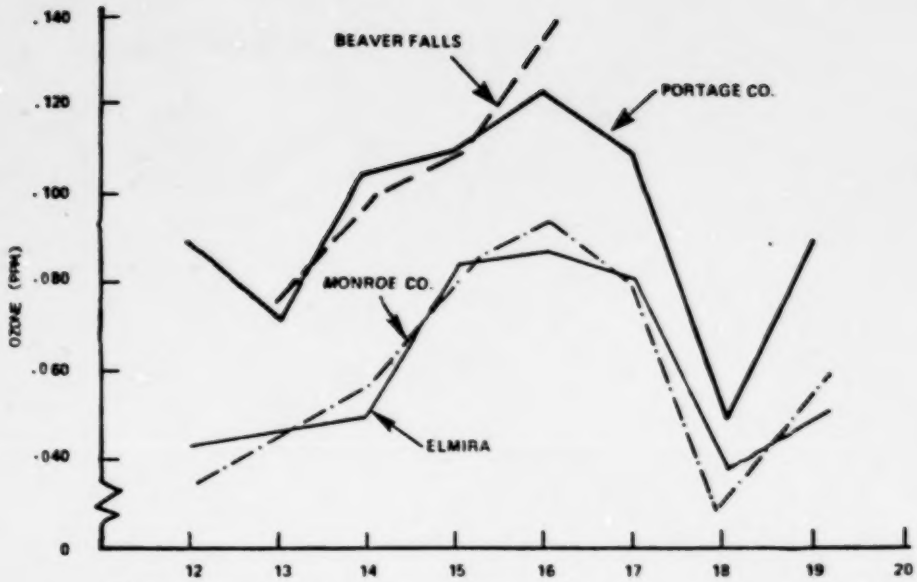


Figure 10. (continued).

The trajectories computed for the study period are shown in Figures 11a-e. On June 14, the trajectories were from the Northwest, passing mostly rural areas in Canada before reaching Green Mountain NF. The path shifted southward during the day, so that air in the vicinity of the site at 1900 had passed near Toronto 24 hours earlier. This southward trend in the direction of flow continued, and, by the next day the air passing Green Mountain NF had traversed Pittsburgh, Cleveland, and Buffalo 24-48 hours

Figure 11a. Trajectory analysis plots at Green Mountain National Forest, VT June 14, 1979.

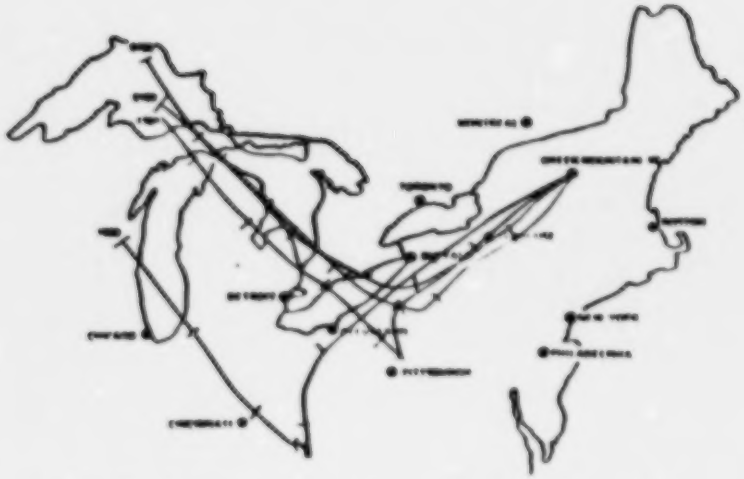


Figure 11b. Trajectory analysis plots at Green Mountain National Forest, VT June 15, 1979.

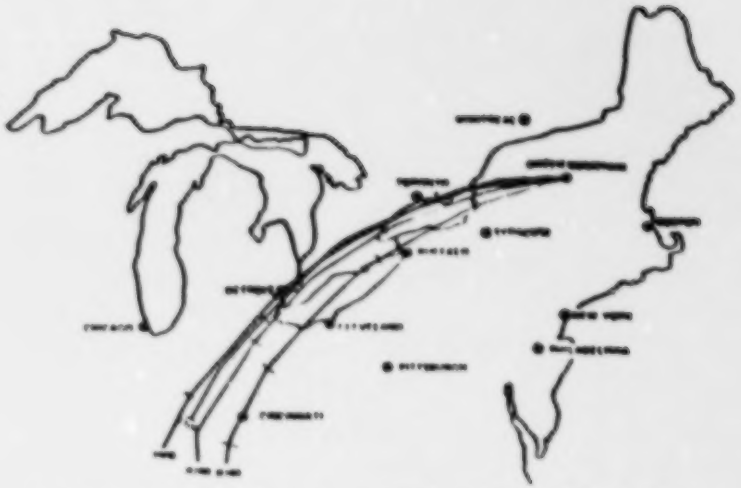


Figure 11c. Trajectory analysis plots at Green Mountain National Forest, VT June 16, 1979.

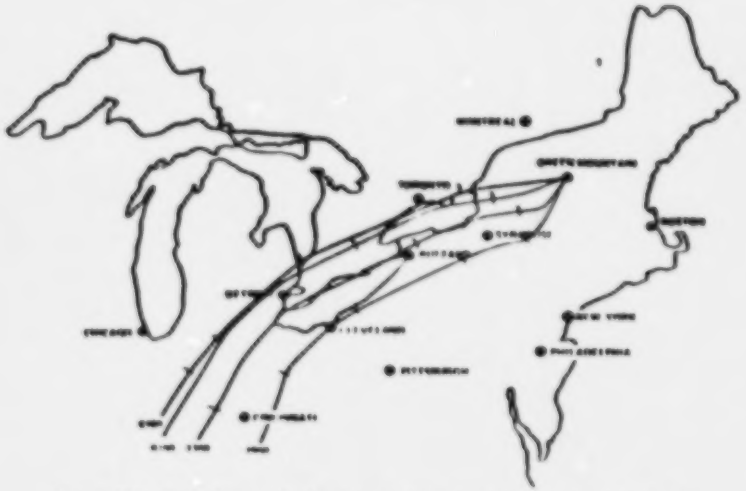


Figure 11d. Trajectory analysis plots at Green Mountain National Forest, VT June 17, 1979.

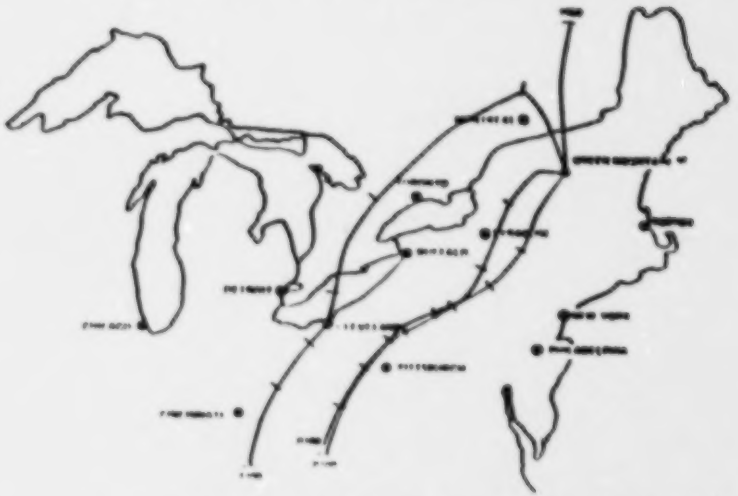


Figure 11e. Trajectory analysis plots at Green Mountain National Forest, VT June 18, 1979.

before, and ozone concentrations exceeded 0.08 ppm. On the following two days (June 16 and 17), trajectories passed several urban areas 24-36 hours upwind from Green Mountain NF, and the peak ozone concentrations of the period were observed. As a cold front advanced through the Northeast and Midwest on the 18th, the ozone concentration dropped, and the directions of arriving trajectories became more random as an air mass from Central Canada brought cleaner air to the region.

The surface wind flow and the trajectory paths implicate long-range transport from urban areas as a contributor to the high ozone levels at Green Mountain NF during this event. The similarity in the patterns of daily maximum ozone at other rural sites in Figure 10 indicates that the episode was fairly widespread along the trajectories crossing Green Mountain NF. In particular, the back trajectories on June 16 indicate that air parcels had been in the vicinity of the Portage Co. and Beaver Falls monitoring sites on the previous day, where similar maximum ozone concentrations were recorded.

Kisatchie NF -- Case Study: April 14-22, 1979

The daily maximum ozone concentrations at Kisatchie and upwind rural sites are shown in Figure 12. Back trajectories of air parcels passing the site during this period are shown in Figures 13a-g.

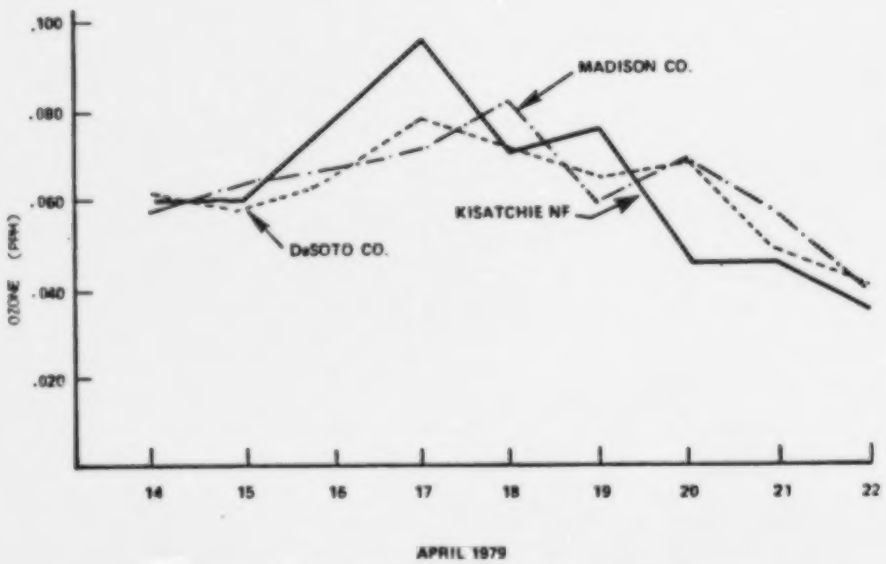


Figure 12. Daily maximum 1-hour ozone concentration (0800-2300): April 14-22, 1979.

Figure 13a. Trajectory analysis plots at Kisatchie National Forest, LA: April 15, 1979.

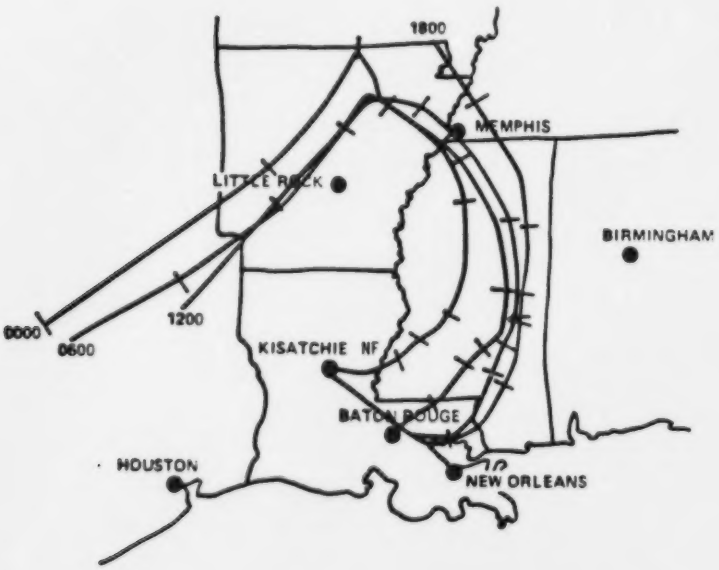


Figure 13b. Trajectory analysis plots at Kisatchie National Forest, LA: April 16, 1979.

Figure 13c. Trajectory Analysis Plots at Kisatchie National Forest, LA: April 17, 1979.

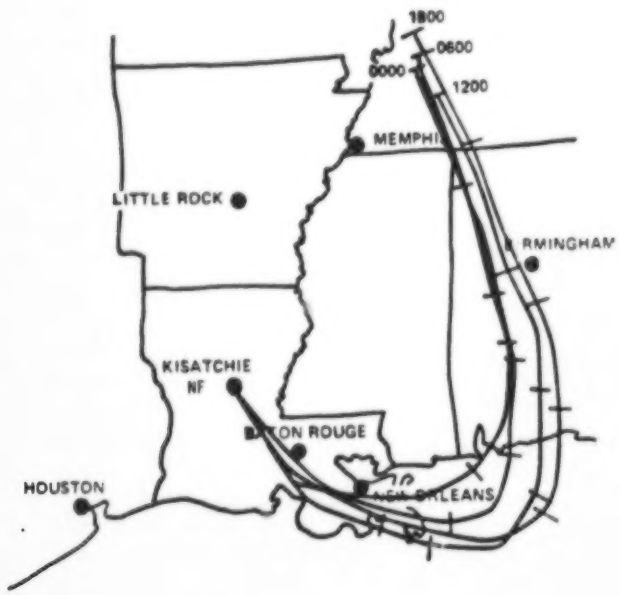


Figure 13d. Trajectory Analysis Plots at Kisatchie National Forest, LA: April 18, 1979.

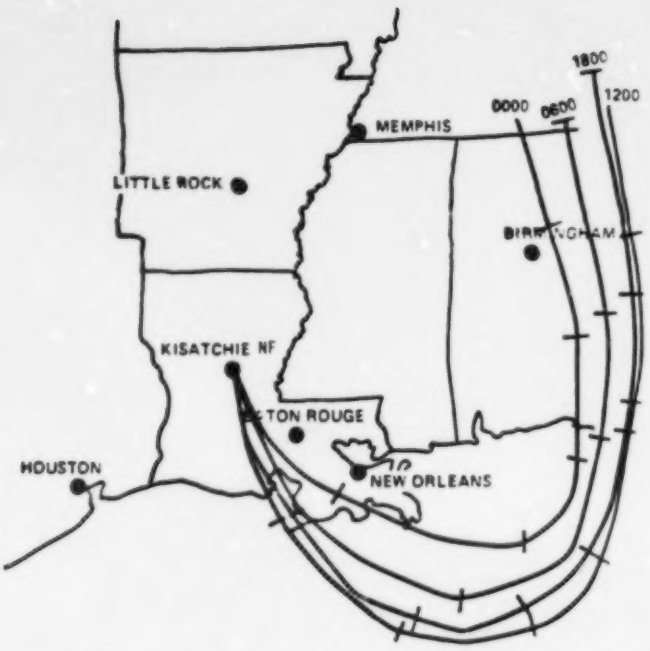


Figure 13e. Trajectory analysis Plots at Kisatchie National Forest, LA: April 19, 1979.

Figure 13f. Trajectory Analysis Plots at Kisatchie National Forest, LA: April 20, 1979.

Figure 13g. Trajectory Analysis Plots at Kisatchie National Forest, LA: April 21, 1979.

At the beginning of the study period, a high pressure system began moving into the Southern United States from the upper plains. The north-south ridge line (center line) of the system remained fairly stationary from Mississippi-Alabama to Southern Canada on April 16 and 17. During this period, skies were partly cloudy, surface winds were from the southeast, and maximum temperatures were in the mid-80's (°F) across Louisiana. Thus, meteorological conditions were generally favorable for photochemical activity. Clouds and rain overspread the area on April 18, reducing ozone concentrations.

On April 15, the day prior to the occurrence of high concentrations, the back trajectories had traversed mostly rural areas within 72 hours of reaching Kisatchie NF. Examination of the trajectories on the two high ozone days, April 16 and 17, indicates that Kisatchie NF was 6-12 hours downwind of the Baton Rouge/New Orleans area on both days. The contention that a portion of ozone at Kisatchie NF on these days was due to emissions from Baton Rouge and New Orleans is supported by comparing the maximum ozone at that site with upwind ozone values. Ozone measurements at Madison, Co. and Desoto Co. sites in Mississippi on April 15 and 16 represent the ozone concentrations which existed 24 hours travel time upwind of Kisatchie NF on April 16 and 17, respectively. The data indicate that maximum ozone at Kisatchie NF was approximately 0.02 ppm higher than the upwind daily

maximum values. Although trajectories on April 18 and 22 passed near Baton Rouge/New Orleans, overcast skies and rainfall preclude the likelihood of significant photochemical activity.

Chequamegon NF -- Case Study: June 12-15, 1979

The daily maximum ozone concentrations at this site, and at other non-urban sites in Wisconsin and in neighboring states, are shown in Figure 14.

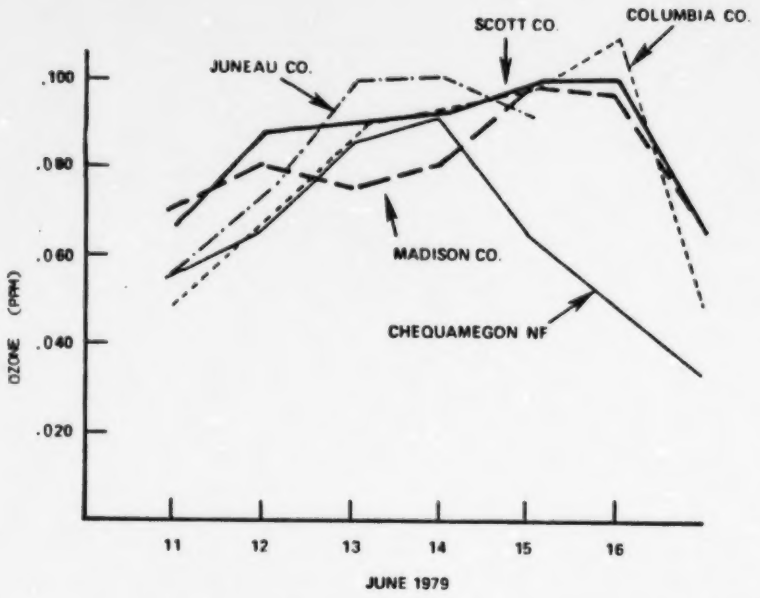


Figure 14. Daily maximum 1-hour ozone concentration (0800-2300): June 11-17, 1979.

On June 12, a rather diffuse stationary front was located across Southern Iowa, and a weak area of high pressure covered the remainder of the upper Midwest. The front moved northward as a warm front on June 14, as the high drifted southeastward and intensified. The circulation around the backside of this system was fairly extensive, with southerly winds from the Gulf Coast to across the Midwest on June 15.

The trajectories of air parcels passing Chequamegon NF during the period are shown in Figures 15a and b. These trajectories, together with the measurements and synoptic meteorological conditions, indicate that the high ozone at Chequamegon NF was not associated with emissions from nearby sources, but was likely caused by long-range transport around the western side of the high pressure system.

Specifically, the 1900 trajectory on June 13 arrived from the air mass south of the stationary front where ozone levels, as indicated by measurements at the Scott and Madison, Iowa sites, were approximately 0.08 ppm the day before. High ozone on June 13 was also measured at the Juneau and

Figure 15a. Trajectory analysis plots at Chequamegon National Forest, WI June 13, 1979.

Figure 15b. Trajectory analysis plots at Chequamegon National Forest, WI June 14, 1979.

Columbia sites, which were upwind of Chequamegon NF on this day. Although surface winds were from the southeast, overcast skies and maximum temperatures only in the low 70's (°F) across Wisconsin and Northern Illinois limited significant ozone formation from relative close upwind urban areas, such as Chicago or Milwaukee or Madison, Wisconsin.

On June 14, the back trajectories were from the south-southwest and passed in the vicinity of Kansas City and Des Moines within 18 hours of reaching Chequamegon NF. However, the strong south to southeast surface winds suggest that transport from other Midwest cities, such as St Louis or Chicago, may have contributed to the high ozone at Chequamegon NF and nearby sites in Juneau Co. and Columbia Co. on this day. The event at Chequamegon NF ended on June 15, as a cold front moved south of the site. However, the front remained north of the Juneau, Columbia, Scott, and Madison sites where ozone levels remained fairly high.

Croatan NF -- Case Study: August 2-12

The daily maximum 1-hour ozone concentrations measured at the Croatan monitoring site during the study period are shown in Figure 16. The data indicate that, although ozone exceeded 0.08 ppm on just one day (August 5), concentrations remained fairly high through August 10. During this period, a weak high pressure area remained quasi-stationary over the Midwest and Southeast. Light wind speeds and maximum temperatures around 90°F provided favorable conditions for the photochemical formation of ozone in these regions.

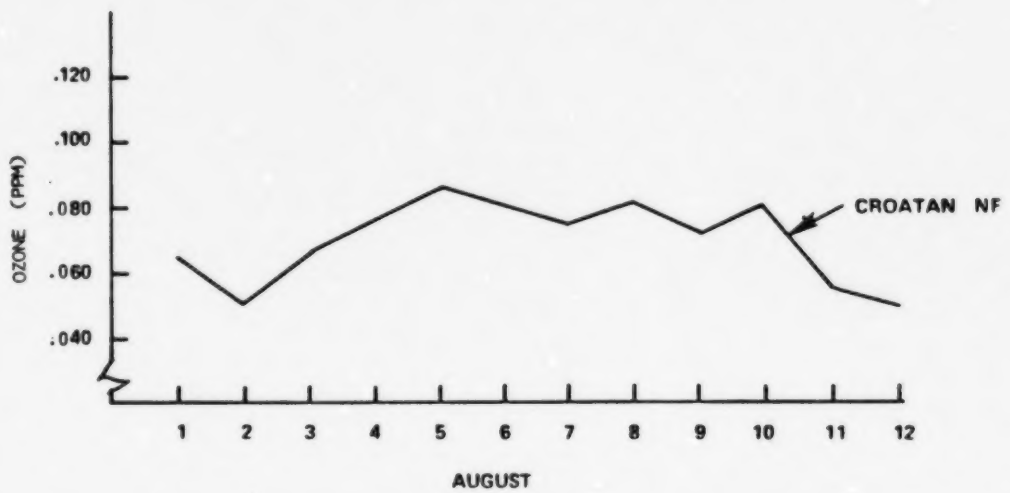


Figure 16. Daily maximum 1-hour ozone concentration (0800-2300): August 1-12, 1979.

The trajectories for the period of August 2 through August 7 are shown in Figures 17a-f. They indicate that air passing Croatan NF on August 2

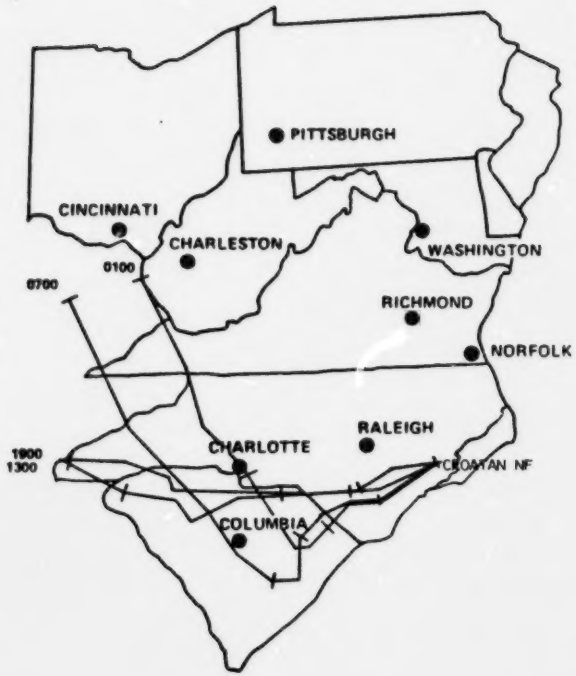


Figure 17a. Trajectory analysis plots at Croatan National Forest, NC: August 2, 1979.

Figure 17b. Trajectory analysis plots at Croatan National Forest, NC: August 3, 1979.

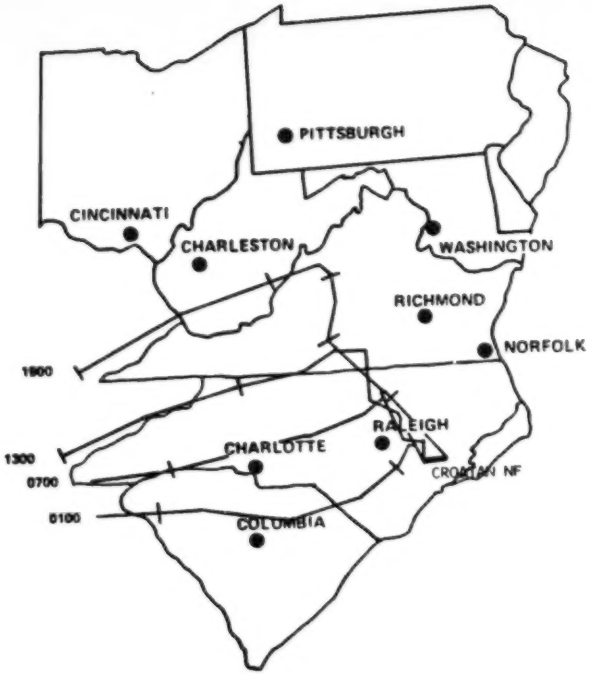


Figure 17c. Trajectory analysis plots at Croatan National Forest, NC: August 4, 1979.

Figure 17d. Trajectory analysis plots at Croatan National Forest, NC: August 5, 1979.

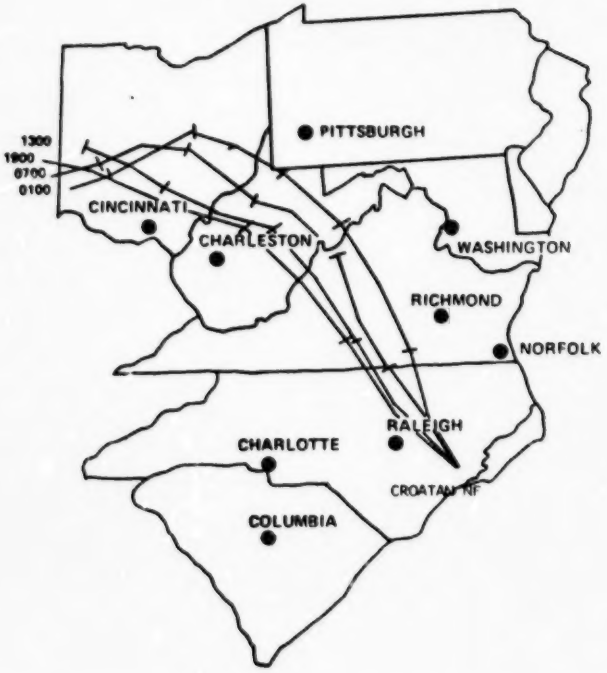


Figure 17e. Trajectory analysis plots at Croatan National Forest, NC: August 6, 1979.

Figure 17f. Trajectory analysis plots at Croatan National Forest, NC: August 7, 1979.

through August 4 traversed mostly rural areas of the Tennessee Valley and the Southeast 60 hours earlier. From August 5 through August 7, the trajectories were from the Midwest. Pittsburgh, Washington, DC and Richmond were 12-48 hours upwind on August 5, the day of highest ozone during the period. The maximum ozone concentrations remained fairly constant between 0.07 and 0.08 ppm through August 10, when trajectories and upper level winds indicated some impact from urban emissions in the Ohio Valley. The daily maximum ozone concentrations dropped to 0.06 ppm on August 11 as rain overspread most of the Eastern United States in association with a low pressure center and frontal system that traced eastward from the Midwest.

LOW OZONE PERIODS

The synoptic-scale meteorological features which influenced the NAPBN sites for the low ozone periods can all be characterized by either a rapid progression of low pressure systems and fronts past the sites and/or cloudy skies and rain. That is, abundant solar radiation at the surface and warm temperatures, which are both conducive to ozone formation, were not prevalent in the vicinity of these sites nor over extensive areas of the Eastern U.S. during the low ozone periods.

The back trajectories for these periods indicate rapid air movement with long daily traverses. Trajectory paths entering from the Northwestern quadrants were observed at the Chequamegon and Green Mountain sites, but trajectory paths were quite variable in direction of approach to the Kisatchie and Mark Twain sites. In all, the back trajectories did not appear to pass in the vicinity of major urban areas on a sustained transport basis during the low ozone periods studies.

SUMMARY OF CASE STUDIES

Numerous events of high ozone concentrations were observed during the spring and summer of 1979 at several NAPBN sites. Further work is needed to establish the sources of ozone during such events. However, the early spring events may be associated with natural sources (i.e., the stratosphere), while anthropogenic sources probably contribute to most of the summer season events. Analysis of selected high ozone events indicates that long-range transport of air mass ozone burden contributed to measured peak concentrations at the remote sites. Also, the impact of relatively nearby urban areas was probable during events at Mark Twain and Kisatchie National Forests.

Examination of selected low ozone periods indicates that meteorological conditions were unfavorable for ozone formation or ozone transport from urbanized areas during such periods.

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